INTEGRATING H_2 INTO OUR NATIONAL AND REGIONAL ENERGY PORTFOLIOS: KEY POLICY ISSUES

Joan M. Ogden

Research scientist

Princeton Environmental Institute

Princeton University

Princeton, NJ

ogden@princeton.edu

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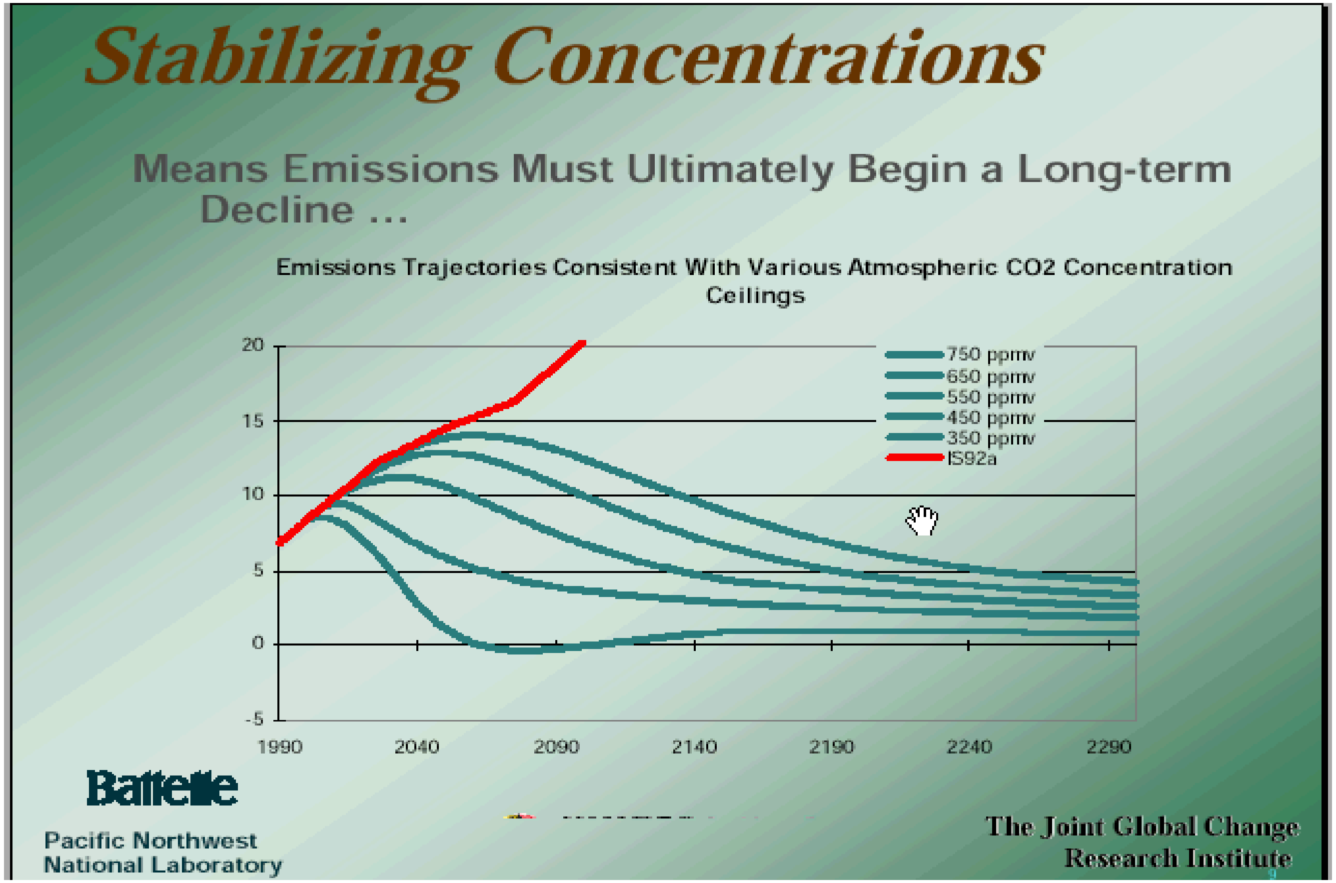
GLOBAL CONTEXT



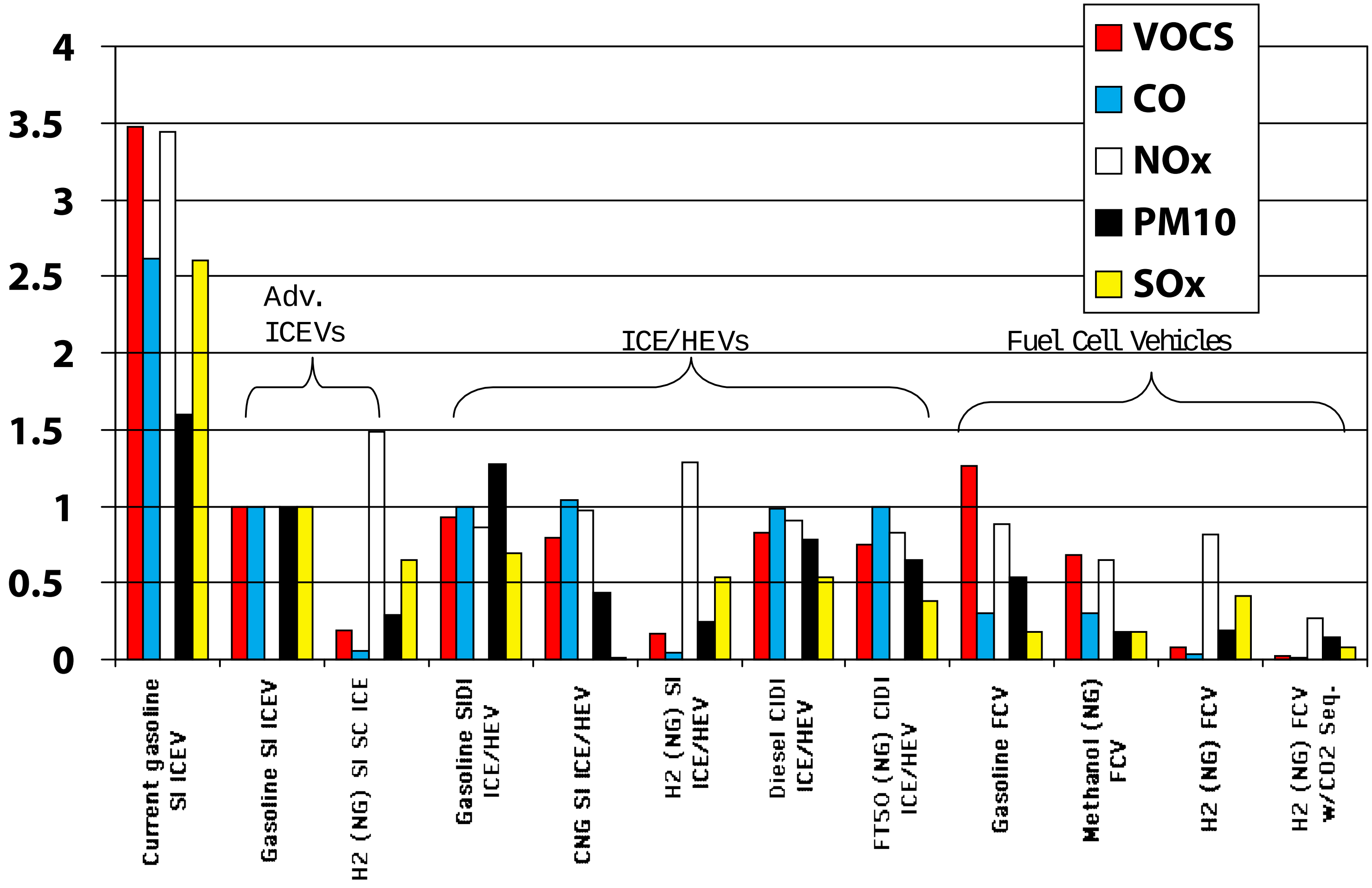
To stabilize CO_2 concentration, need to decarbonize the energy system at several times the historical rate of 0.3%/y. Even if electric sector is completely decarbonized by 2100, stabilization at 550 (450) ppm => 3 (5) fold reduction in carbon emissions from direct fuel use vs. IS92a.

WHY CONSIDER H_2 AS A FUTURE ENERGY CARRIER?

- Zero or near-zero emissions at point of use
- Low to zero full fuel cycle primary emissions of both air pollutants and greenhouse gases (e.g. H_2 fuel cell vehicles offer lowest well-to-wheels emissions of any fuel/engine option)
- H_2 can be made from widely available primary resources (fossil, renewable, nuclear)
- Hydrogen offers **<u>MULTIPLE</u>** benefits
- Rapid progress in H_2 and fuel cell technologies

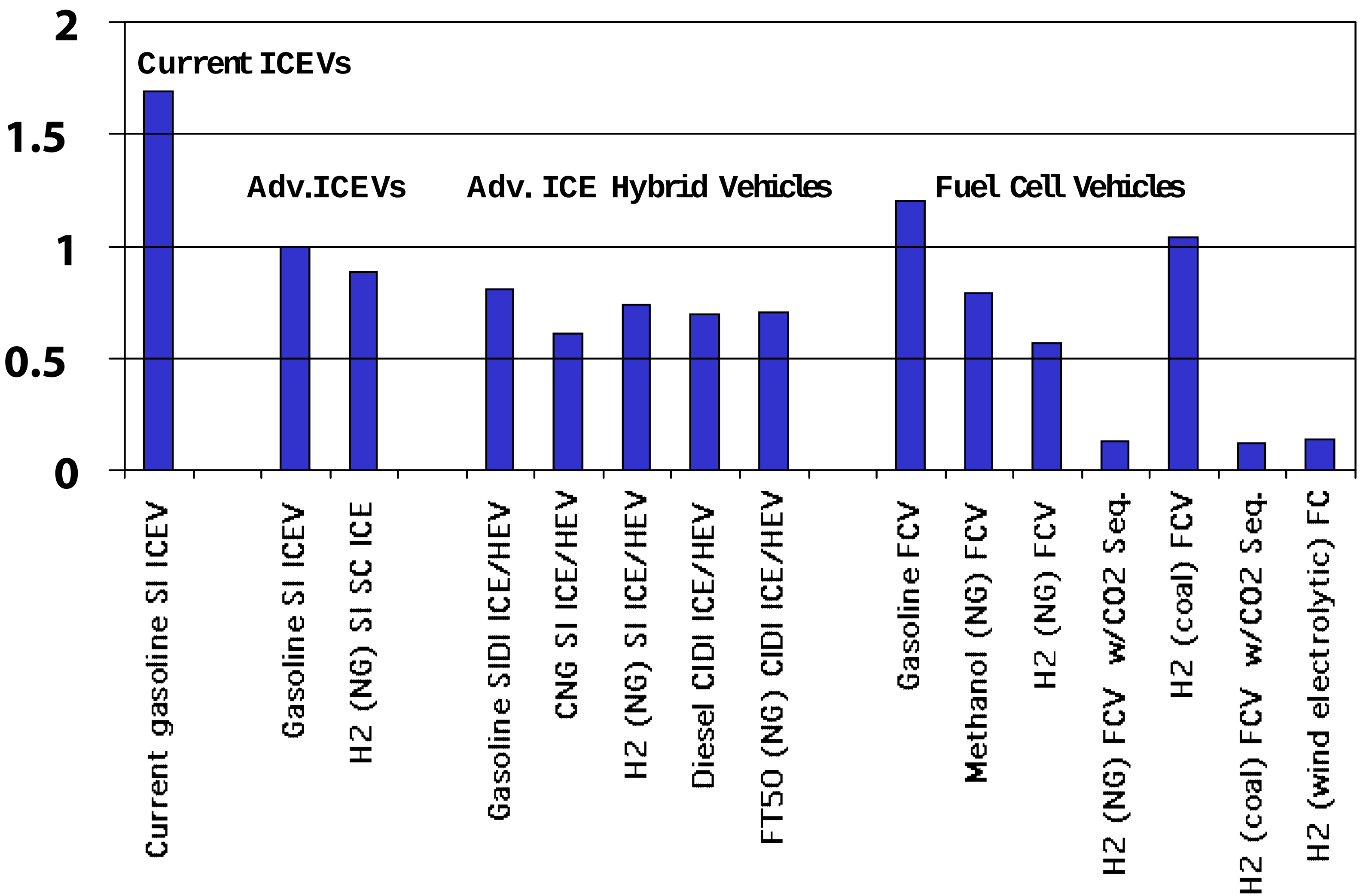
Full Fuel Cycle Emissions of Air Pollutants

(Emissions from Alternative Fueled Automobiles Normalized to Adv., Lightweight Gasoline ICEV)



FULL FUEL CYCLE GREENHOUSE GAS EMISSIONS

(Normalized to Adv. Lightweight 46 mpg Gasoline ICEV)

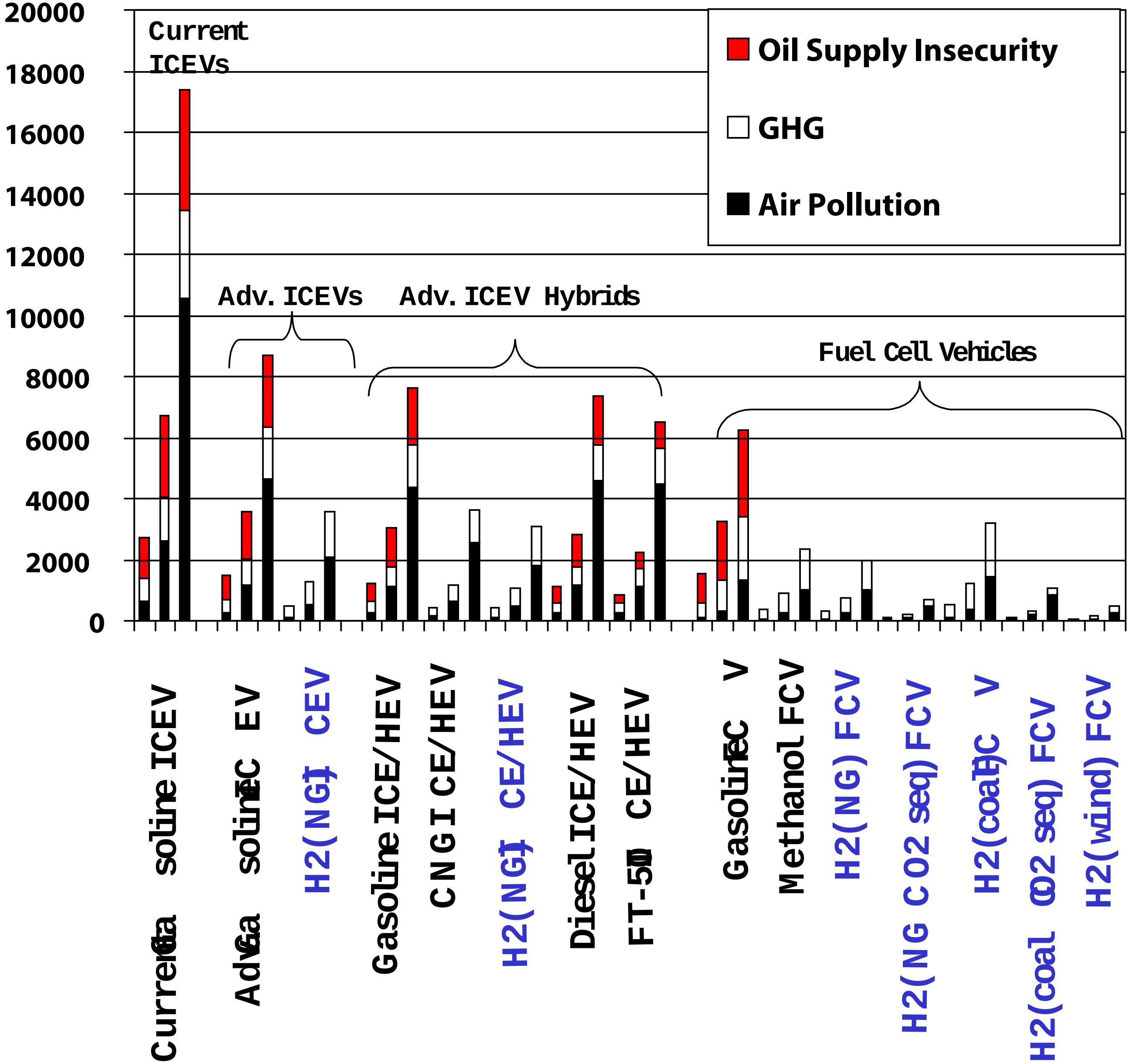


EXTERNAL COSTS OF ENERGY

<u>THERE ARE LARGE UNCERTAINTIES</u>

- **Greenhouse Gas Emissions** \$50-200/tC (cost of reducing C emissions from energy system)
- **Air Pollution Damage Costs** associated with energy production and use (primarily long-term health effects of particulates). Uncertainty in cost (d.t. uncertainties in emissions from sources, atmospheric transport and chemistry, dose, health and other damage effects, economic value of damages) ranges over 1-2 orders of magnitude.
- **Oil Supply Insecurity.** For US, \$20-60 billion/y. (depending on how this is allotted to supply, ~\$0.35-1.05/gal gasoline)

Range of Lifetime Externality Costs($) for Alternative Fueled Automobiles (Low, Mid and High Estimates)



EXTERNALITIES COULD BECOME AN IMPORTANT DRIVER FOR H_2

- H_2 vehicles have the lowest overall externality costs of any vehicle/fuel options.
- H_2 could address many issues simultaneously.
- It is highly uncertain today what precise economic values should be assigned to external costs of energy (climate change, health effects from air pollution, oil supply insecurity). However, H_2 is the least sensitive to these costs.

BARRIERS TO A HYDROGEN ECONOMY

- current lack of a H_2 infrastructure; “chicken and egg” problem
- current high cost of H_2 end-use technologies
- technical maturity: adapting current technologies for a H_2 energy economy could speed progress (e.g. onboard H_2 storage, small scale H_2 production systems, fossil H_2 production with CO_2 sequestration); need for codes and standards
- lack of policies reflecting the external costs of energy

MID-ATLANTIC REGIONAL CONTEXT

- Several non-attainment areas for ozone, CO, particulates
- State Climate Change Plans being developed
- Clean Cities programs (Philadelphia, Pittsburgh, Baltimore, DC, DE, North Jersey, West Virginia, Hampton Roads)
- Significant alternative fuel vehicle demonstration programs, and availability of alternative fuels like CNG.
- Home to H_2 suppliers and users (chemical and refinery operations), fuel cell and H_2 energy tech. companies,
- Mid-Atlantic region is large energy market, accounting for ~14% of passenger cars and 11% of light trucks in US.

H_2 ECONOMY: MID-ATLANTIC REGION

- Population = 30 million people
- ~18 million cars; ~7 million light trucks; ~2 million heavy trucks and buses (Ave. miles/yr/vehicle = 11,900; ave. fuel economy for Light Duty Vehicles = 20 mpg)
- Energy use 11 Trillion BTU/y (27% coal, 19% NG, 17% gasoline, 14% nuclear, 9% Distillate fuel)
- Installed Electric capacity = 95,000 MWe, ~45% coal-fired, 17% nuclear, ~3 kWe/person
- If all LDVs converted to H_2 FCVs, regionally
  - NG use would increase by ~29% OR
  - Coal use would increase by ~27% (~60 CO_2 injection wells, each disposing of 2500 tonne/day would be needed for CO_2 produced in coal->H_2 plants) OR
  - Electric power ~ 20,000 MWe would be needed on continuous basis. Or ~ 40,000 MWe off-peak power for 12 h/d.

POTENTIAL APPLICATIONS FOR H_2 VEHICLES IN MID-ATLANTIC REGION

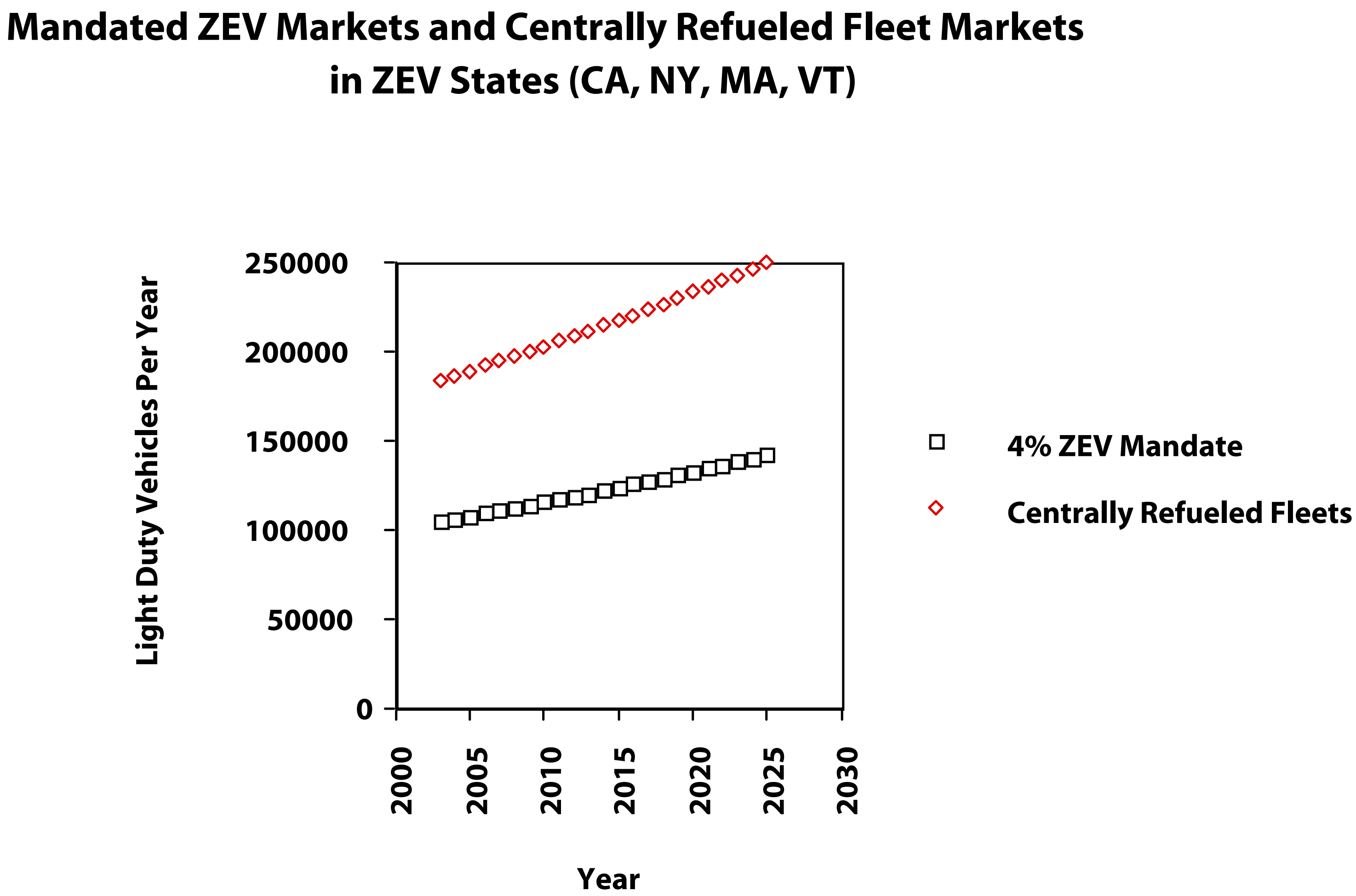
- Transit buses
- Other Centrally Refueled Fleet vehicles
- General Automotive Markets: Light Duty Vehicles

FLEETS ARE ATTRACTIVE INITIAL MARKETS FOR H_2 VEHICLES

- For centrally refueled fleets, only a limited fuel supply infrastructure is needed.
- High level of technical competence for personnel operating H_2 refueling station.
- Current compressed gas H_2 storage systems would provide adequate range for fleet service (analogous to CNG)

POTENTIAL ROLE OF CENTRALLY REFUELED FLEETS IN DEVELOPMENT OF H_2 AS A TRANSPORTATION FUEL

- In the US, ~ 0.8 million new light duty vehicles are sold into centrally refueled, non-rental fleets each year.
- Globally, centrally refueled urban transit bus markets could also be large (>200,000 buses/year by 2010).
- Centrally refueled fleet markets are potentially large enough to help "buy down" the cost of H_2 technologies such as fuel cell vehicles over the next decade via mass production, if they capture major fraction of these markets. (Mandated US ZEV and AFV markets might be large enough to accomplish significant cost reduction of H_2 FCVs.)



Mandated ZEV Markets and Centrally Refueled Fleet Markets
in ZEV States (CA, NY, MA, VT)
Light Duty Vehicles Per Year
250000
200000
150000
100000
50000
0
2000
2005
2010
2015
2020
2025
2030
Year
4% ZEV Mandate
Centrally Refueled Fleets

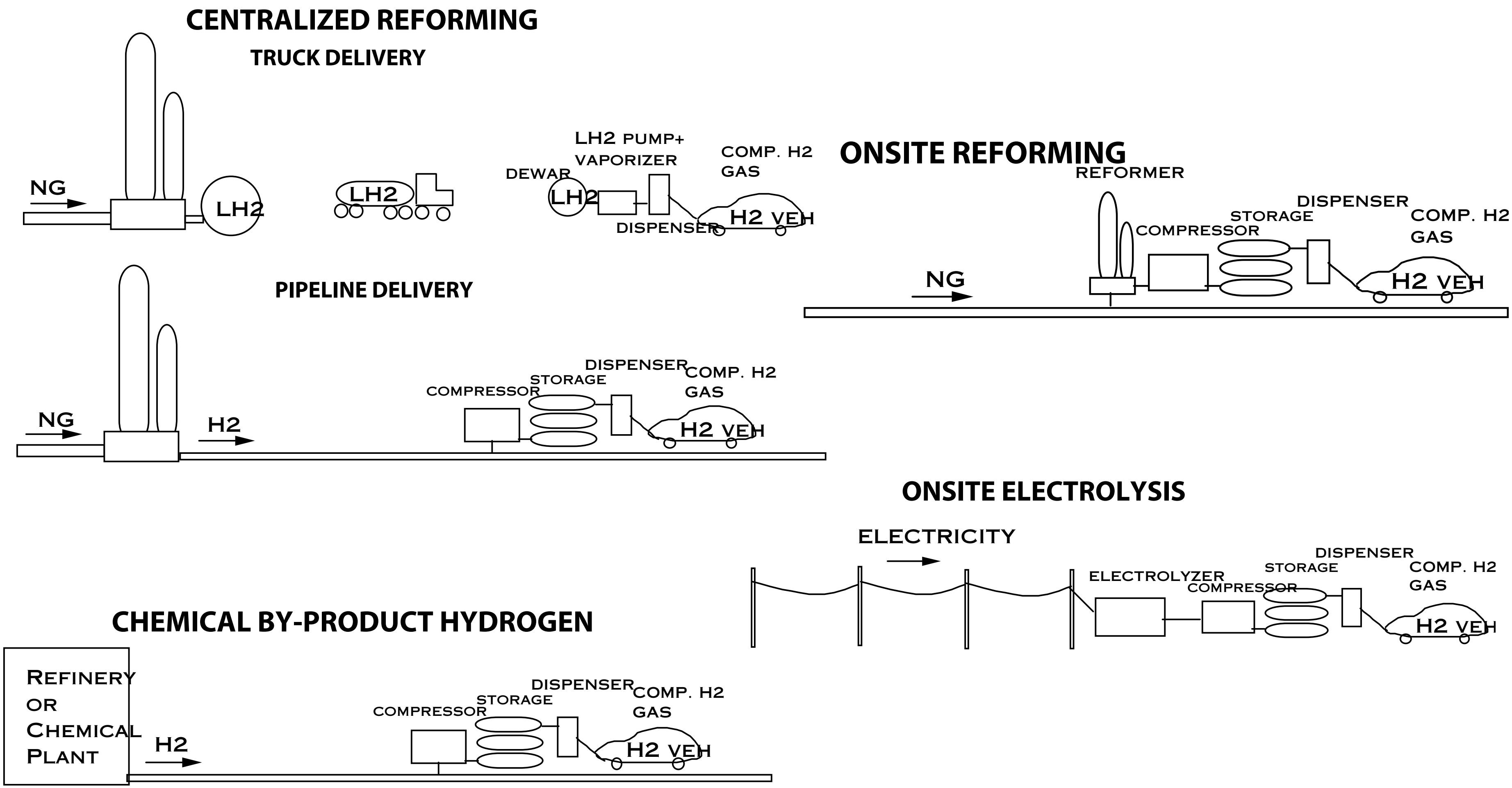
Fleet Vehicles in the Mid-Atlantic Region

(Mid-Atlantic Region has ~13% of US fleet LDVs

or ~0.1 million new centrally refueled LDVs per year.)

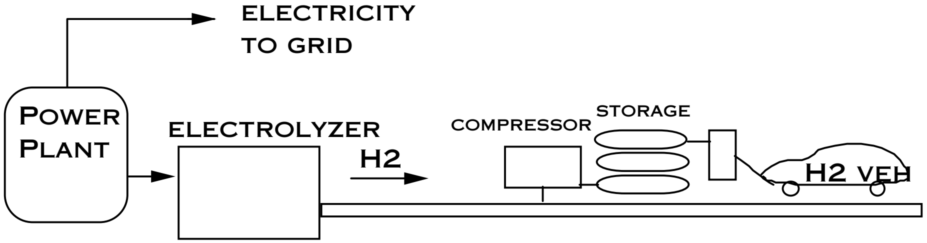
	TOTAL # FLEETS 10+ VEH	FLEET AUTOS (% TOTAL AUTOS)	FLEET LIGHT TRUCKS (% TOTAL LT. TRUCKS)	ALL FLEET VEHICLES INCLUDING HEAVY TRUCKS AND BUSES (% TOTAL VEHICLES)
PA	6060	166715	200728	546352
NJ	4001	139493	157077	416552
DE	471	11403	20510	49267
MD	2277	78418	112233	262599
VA	3094	108253	122316	329802
W VA	920	24356	45118	85987
DC	269	8160	19533	43804
TOTAL	17,092	536,798 (3%)	677,515 (9%)	1,734,363 (7%)

Near term H_2 Supply Options

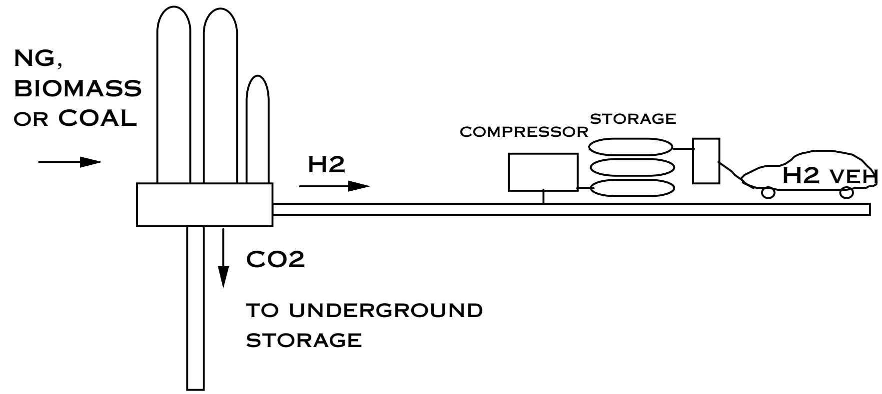


Long term H_2 Supply Options

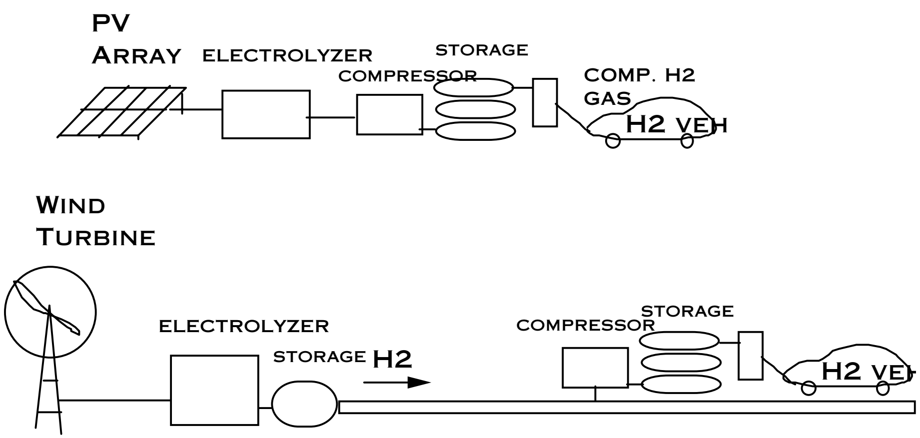
CENTRALIZED PRODUCTION OF ELECTROLYTIC H2



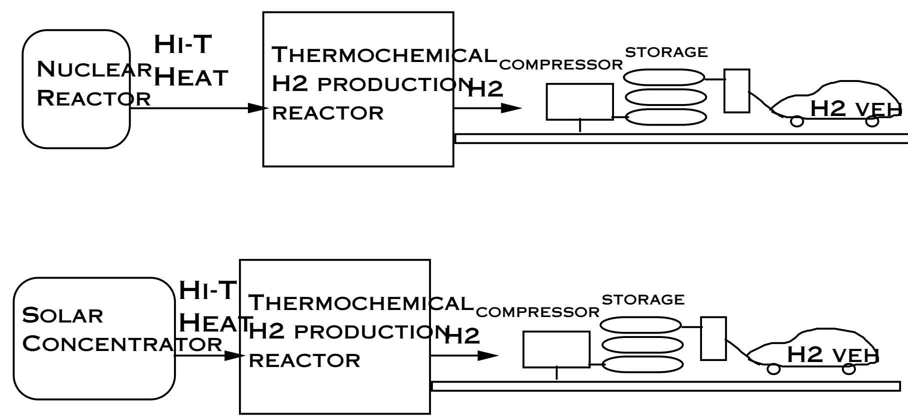
H2 FROM HYDROCARBONS w/CO2 SEQUESTRATION



SOLAR or WIND ELECTROLYTIC H2



H2 PRODUCTION VIA THERMOCHEMICAL CYCLES POWERED BY NUCLEAR OR SOLAR HEAT



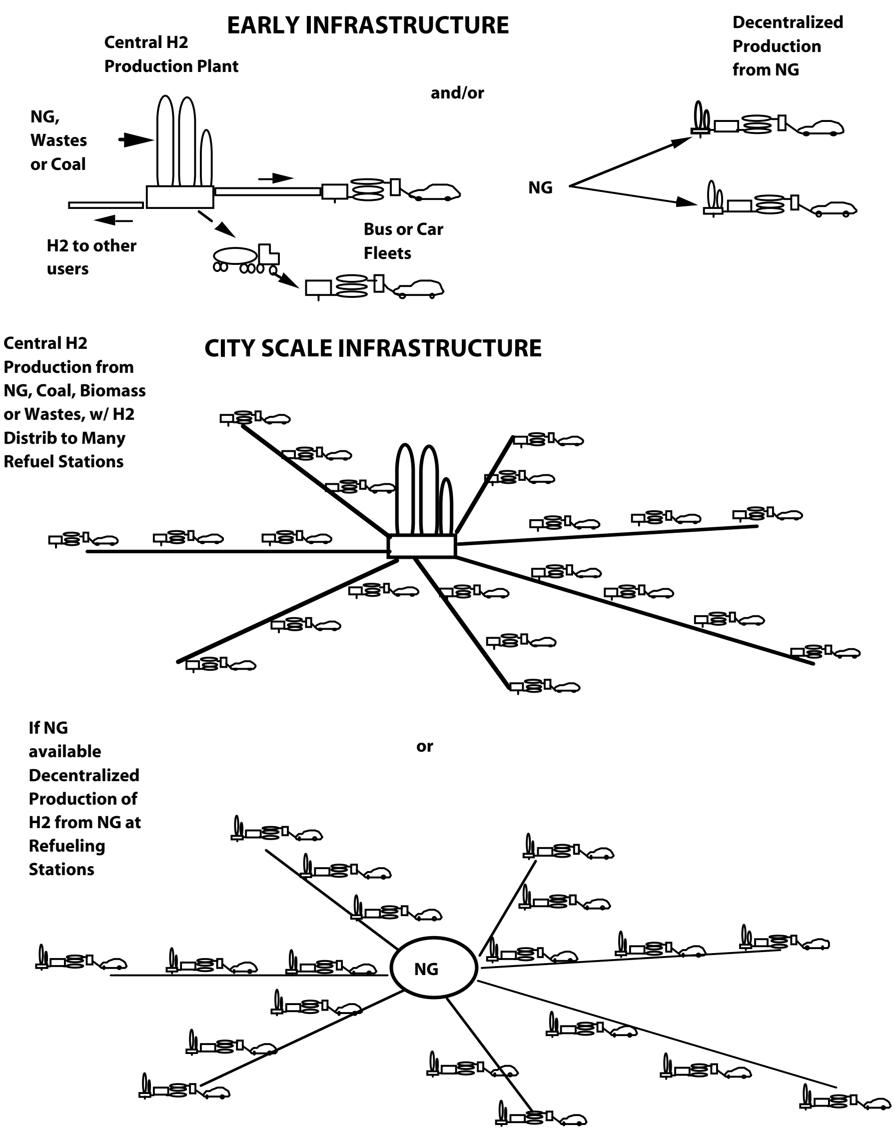
H_2 SUPPLY AND DEMAND

H_2 Demands	KG H_2/DAY		
1 H_2 FC Car (82 MPG, 11,000 MI/Y)	0.375		
1 H_2 FC Bus (7 MPGE, 50,000 MI/Y)	20		
100-1000 H_2 FC Car Fleet Cars (82 MPG, 17,000 MI/Y)	58-580		
100-1000 FC Buses	2000-20,000		
100,000 cars (~1% of cars in LA)	37,500		
1 million cars (~10% of cars in LA)	375,000		
10 million cars (~100% cars in LA)	3,750,000		
H_2 Supplies	**KG H_2/DAY**	**Size of H_2 FC Car Fleet Supported**	**Size of H_2 FC Bus Fleet**
Compressed H_2 Gas Truck (1/day)	420	1120	21
Liquid H2 Truck (1/day)	3600	9600	180
Onsite Electrolyzer	2.4-2400	6.4-6400	0.12-120
Onsite Steam Methane Reformer (SMR)	240-4800	640-12,800	12-240
Municipal Solid Waste Gasifier (waste from city of 100,000 people)	12,000	32,000	600
Industrial scale steam methane reformer	48,000 - 480,000	128,000 - 1,280,000	2400 - 24,000
Coal gasifier H_2 plant w/CO_2 seq.	150,000 - 600,000	400,000 - 1,600,00	7500 - 30,000
H_2 from 10% of NG Flow into LA	1,700,000	4,533,333	85,000
H_2 from 1000 MW off-peak power	240,000	640,000	12,000

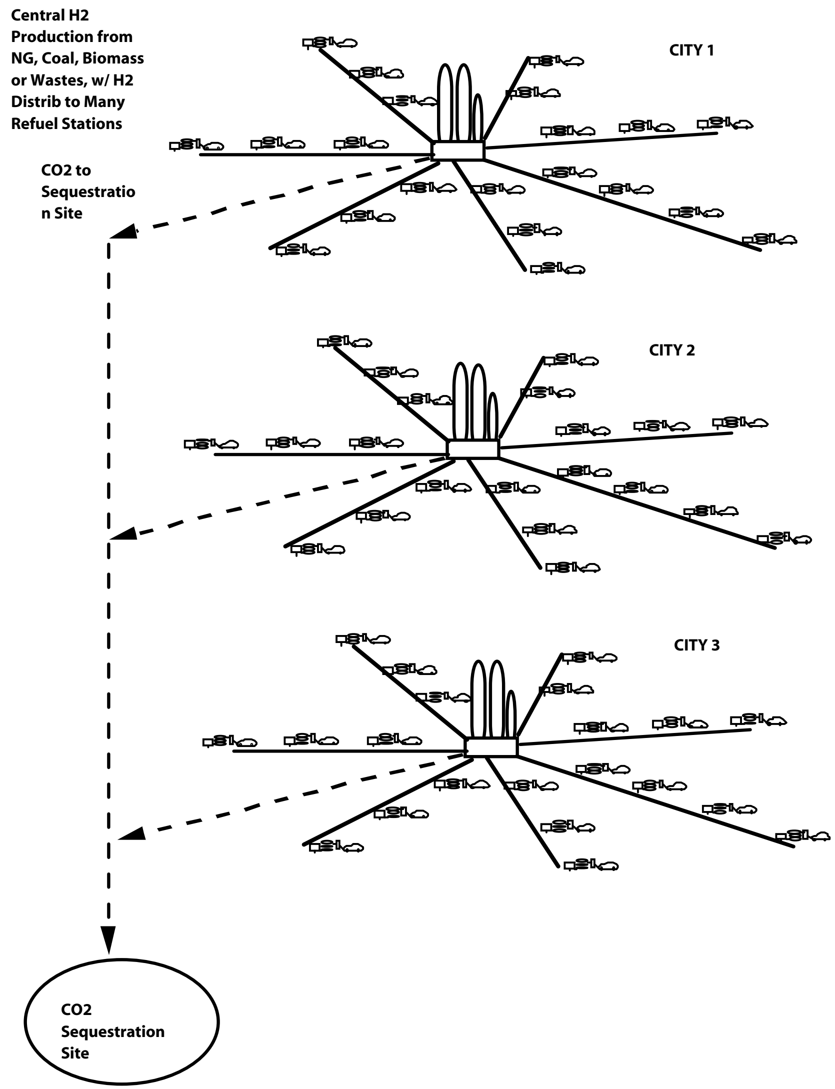
Conversion Factors:

1 kg H_2 = 0.14 GJ (HHV) ~1 gallon gasoline; 1 tonne/day = 0.4 million scf/d

1 kW H_2 = 0.6 kg H_2/day; 1 FC Car requires ~0.6 kW H_2 production capacity


EARLY INFRASTRUCTURE
Central H2 Production Plant
NG, Wastes or Coal
H2 to other users
Bus or Car Fleets
and/or
Decentralized Production from NG
NG
CITY SCALE INFRASTRUCTURE
Central H2 Production from NG, Coal, Biomass or Wastes, w/ H2 Distrib to Many Refuel Stations
or
If NG available Decentralized Production of H2 from NG at Refueling Stations
NG

HYDROGEN ENERGY ECONOMY W/CO2 SEQUESTRATION



POLICIES WILL PROBABLY BE REQUIRED TO BRING ABOUT A H_2 ECONOMY, INCLUDING VALUATION OF EXTERNALITIES

In world where H_2 is widely used externalities will be more important than they are now. Political will and markets will evolve together, reflecting profound changes in how we view energy as a society.

Factors that could accelerate adoption of H_2: 1) technical breakthroughs, and 2) potential market pull of fundamentally new products and services enabled by the use of H_2 or fuel cells.

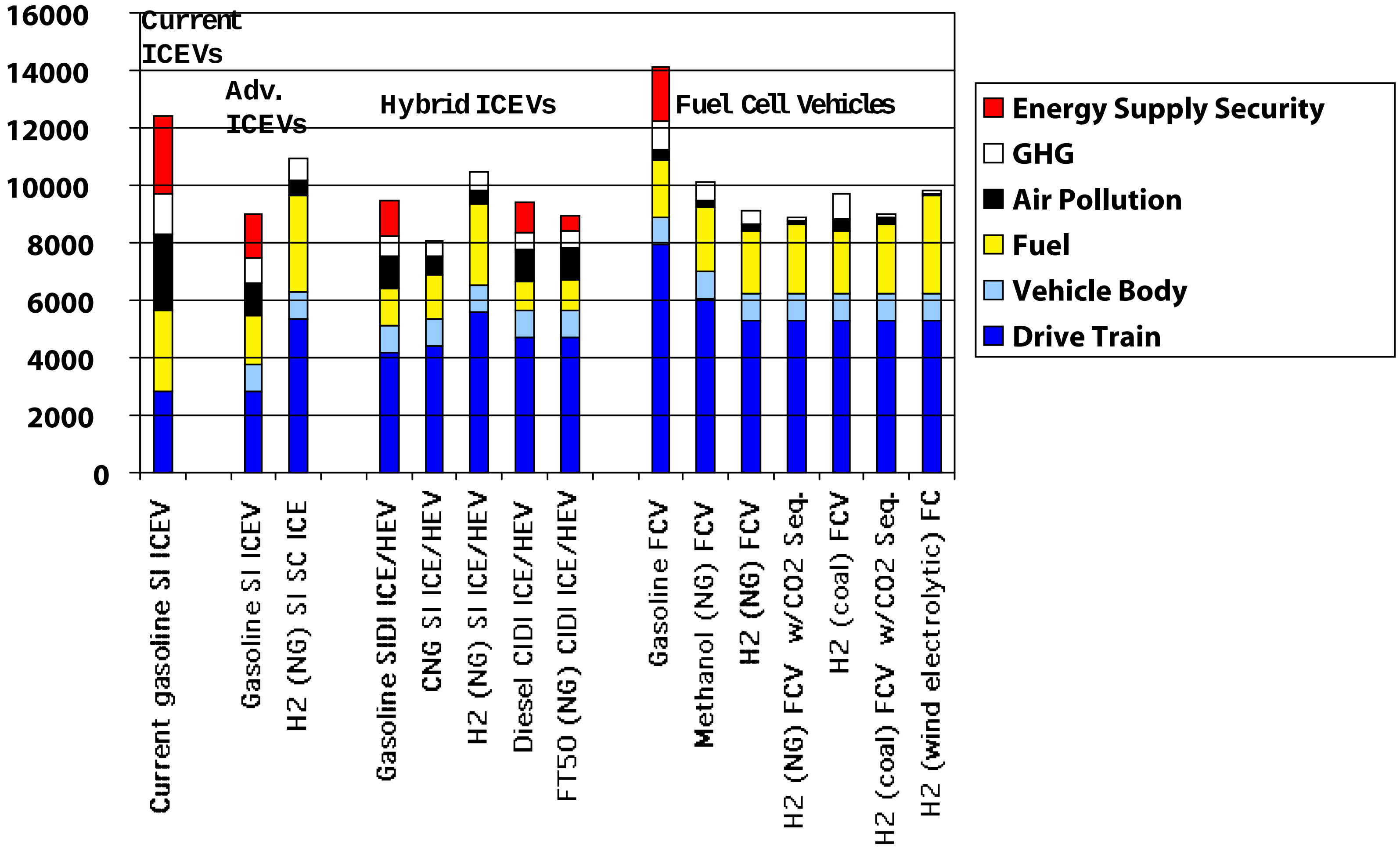
POLICIES TO ENCOURAGE USE OF H_2

- R&D on key concepts, where a breakthrough could speed the adoption of H_2 (e.g. H_2 storage, small scale H_2 production, CO_2 sequestration)
- Demonstration of H_2 production, refueling infrastructure and end-use technologies; development of codes and standards.
- Policies to encourage "buy-down" of H_2 technologies such as fuel cells and encourage H_2 infrastructure development. For example, use of H_2 in ZEV fleets.
- Policies to value externalities: emissions standards (air pollutants and Carbon), feebates for clean efficient vehicles, fuel economy standards, gasoline tax, carbon tax

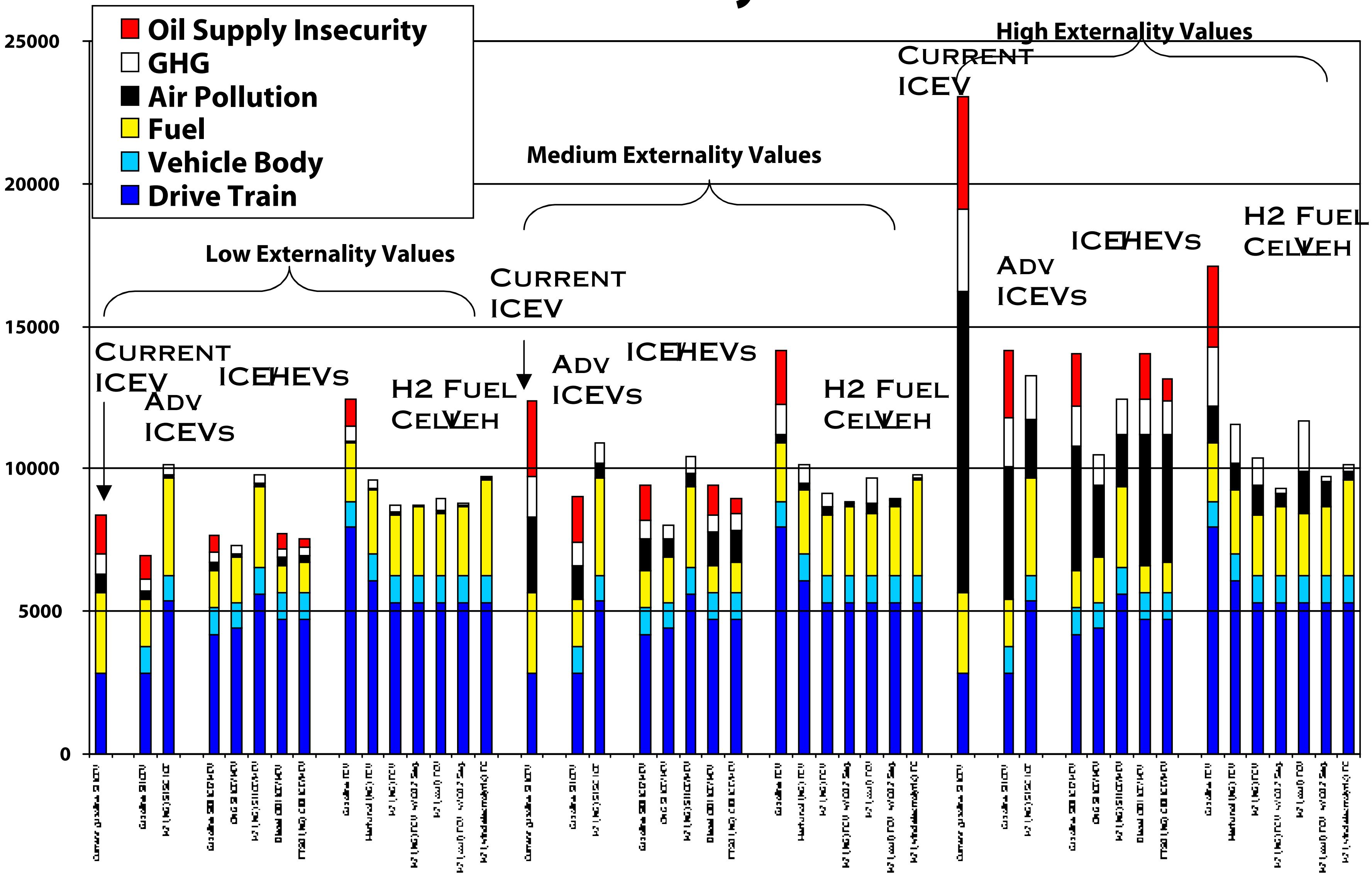
CONCLUSION

- H_2 and fuel-cell technologies, although high-risk and long-term, have a potentially very high payoff. Therefore, they deserve significant government support now, so that they will be ready in 15-20 years, if and when we need to deploy them widely.
- Consistent policies are needed to encourage use of cleaner transportation systems with lower carbon emissions and to move away from our almost exclusive dependence on crude oil-derived transportation fuels
- Comprehensive strategy: Encourage use of clean, efficient internal combustion engine vehicles in the near term, coupled with a longer term strategy of research, development and demonstration of H_2 and fuel cells.

Societal Lifecycle Cost ($) for Alt. Fueled Cars Including Drive Train, Lightweight Body, Fuel, and Externality Costs for Air Pollution, Greenhouse Gases, & Oil Supply Insecurity



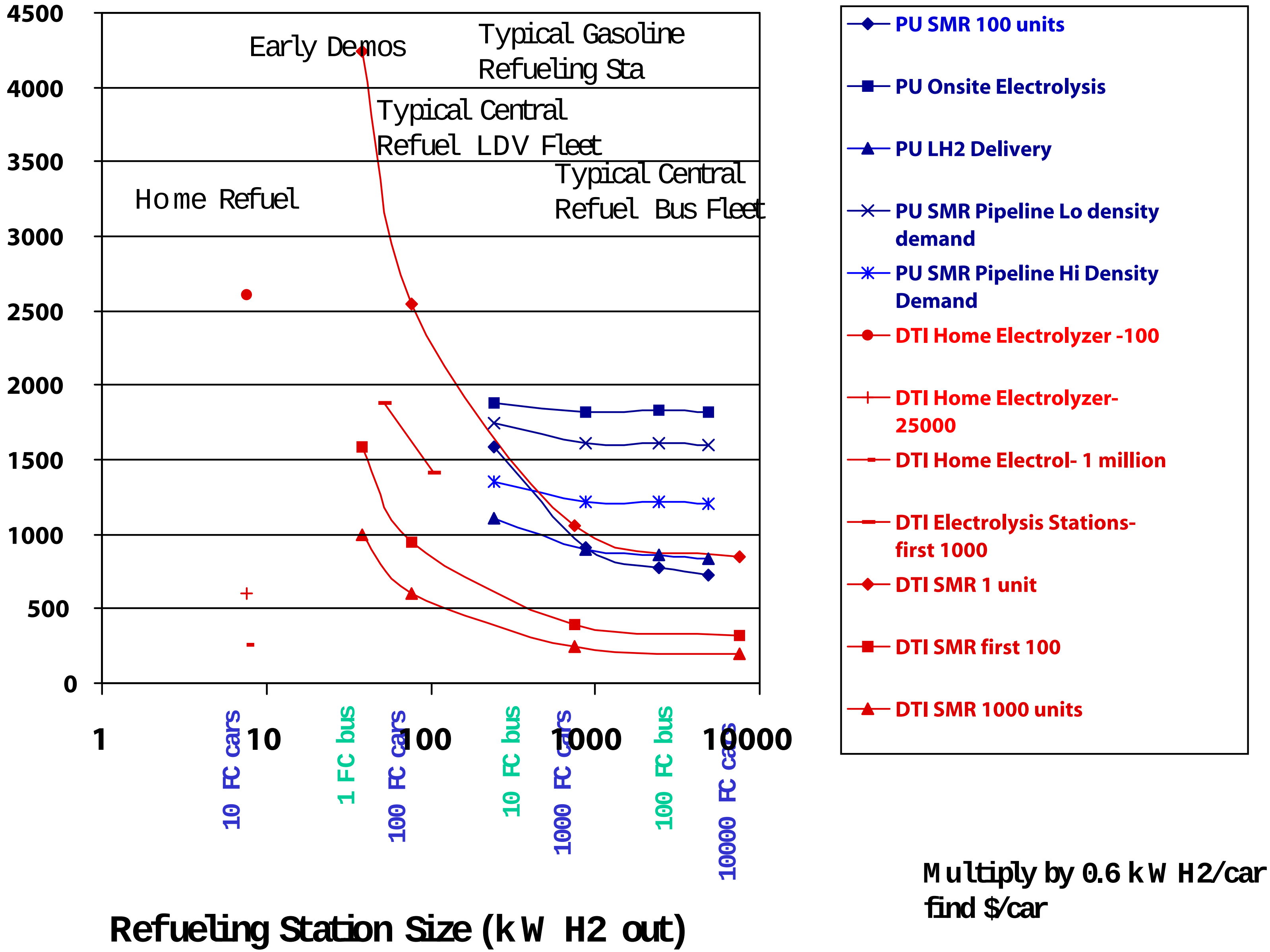
Lifecycle Cost($) of Alternative Fueled Automobiles for Low, Median and High Externality Values



FLEET MARKETS IN THE US

- ~ 12 million vehicles in the US (4 million cars, 5 million light trucks, 3 million heavy trucks & buses) are in fleets of 10+
- ~ 75-80% of large business, utility and government LDV fleets and >90% of bus fleets are centrally refueled
- About 40% of fleet cars are in daily rental use (these are not centrally refueled and are sold after 1-2 years), the rest are centrally refueled and are typically kept for 100,000 miles.
- 90% of centrally refueled LDVs are in fleets of >100 cars. Typical size 100-1000 vehicles.
- In the US, we estimate that ~ 0.8 million new light duty vehicles are sold into centrally refueled, non-rental fleets each year.
- Ave. fleet LDV travels ~50-100% more miles/yr than ave. passenger LDV, so fleets use proportionally more energy)

Infrastructure Capital Cost ($/kW) vs. Station Size



Multiply by 0.6 kW H2/car to find $/car